

An Approach to Detect and Mitigate Ice Particle Accretion in Aircraft Engine Compression Systems

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Overview

- Problem of Engine Power Loss
- Modeling Engine Icing Effects
- Detection of Ice Accretion
- Potential Mitigation Strategies
- Future Work

Problem of Icing Induced Power Loss

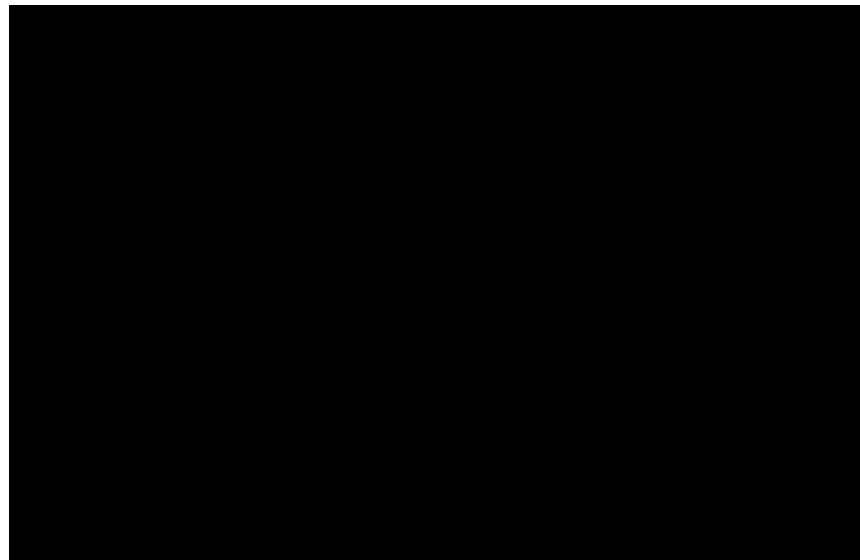


- More than 150 power loss events reported in last 20 years in High Ice Water Content conditions
 - Temporary or sustained power loss, uncontrollability, engine shutdown
- Many possible causes of power loss:
 - Compressor surge
 - Flame-out due to combustor ice ingestion
 - Damage due to ice shedding
 - Sensor icing
 - Engine rollback

Problem of Icing Induced Power Loss



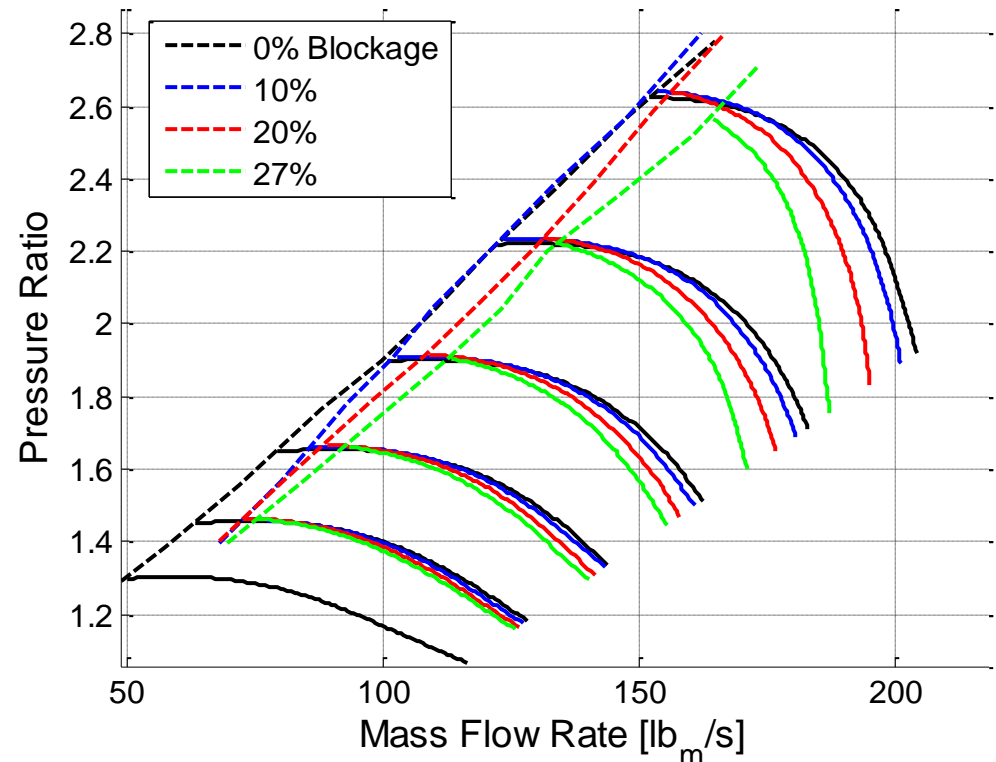
- Ice crystals are believed to enter the core, melt, and accrete on engine components
- No pilot reports of weather radar returns
- No observations of airframe icing



Video courtesy of NASA GRC

Modeling of Engine Icing Effects

- Low Pressure Compressor (LPC) maps with various quantities of ice blockage in the 2nd row stator
- Integrated into C-MAPSS40k
 - Linear interpolation between maps



Underlying data from:

Jorgenson, P.C.E., Veres, J.P., May, R.D., Wright, W.B.,
“Engine Icing Modeling and Simulation (Part I): Ice Crystal
Accretion on Compression System Components and Modeling
its Effects on Engine Performance,” 2011-38-0025, SAE
International Conference on Aircraft and Engine Icing and
Ground Deicing, Chicago, IL, Jun 13-17, 2011.
doi:10.4271/2011-38-0025

Detection of Engine Icing

- Typically 5 – 7 control sensors present in an engine
- Icing causes a change in the LPC operational characteristics
 - Decrease in flow rate
 - Generally a decrease in efficiency
 - Decrease in surge line
- Goal: use the available sensors to estimate the change in LPC performance
- Constraint: Must be computationally simple and have small memory footprint

Detection of Engine Icing - Approach



- Linear estimator
 - Estimate shift in LPC efficiency and LPC flow capacity
 - Sensor residuals are based on corrected fan shaft speed, corrected core shaft speed, and corrected EGT
- Assumptions:
 - No other component faults
 - This ensures that all changes in engine operation are due to ice accretion

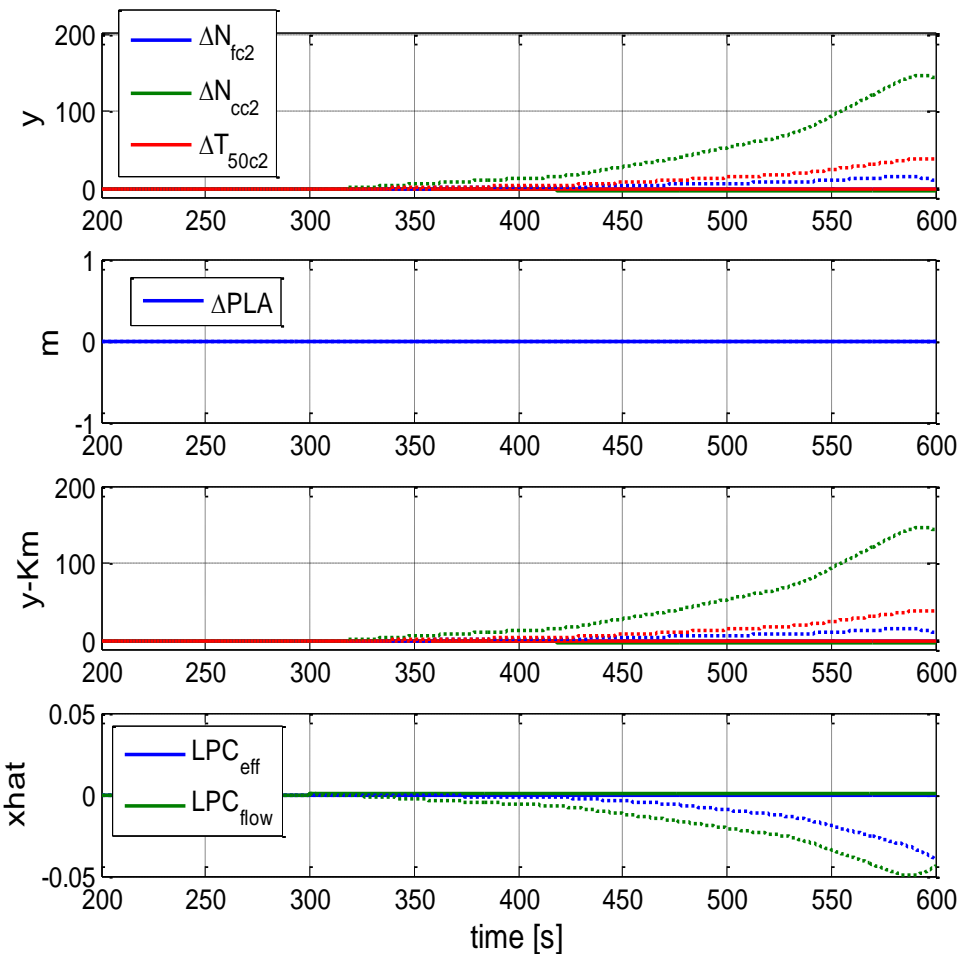
$$\Delta y = H\Delta x + K\Delta m + \omega$$

$$\Delta \hat{x} = (H' R^{-1} H)^{-1} H' R^{-1} (\Delta y - K\Delta m)$$

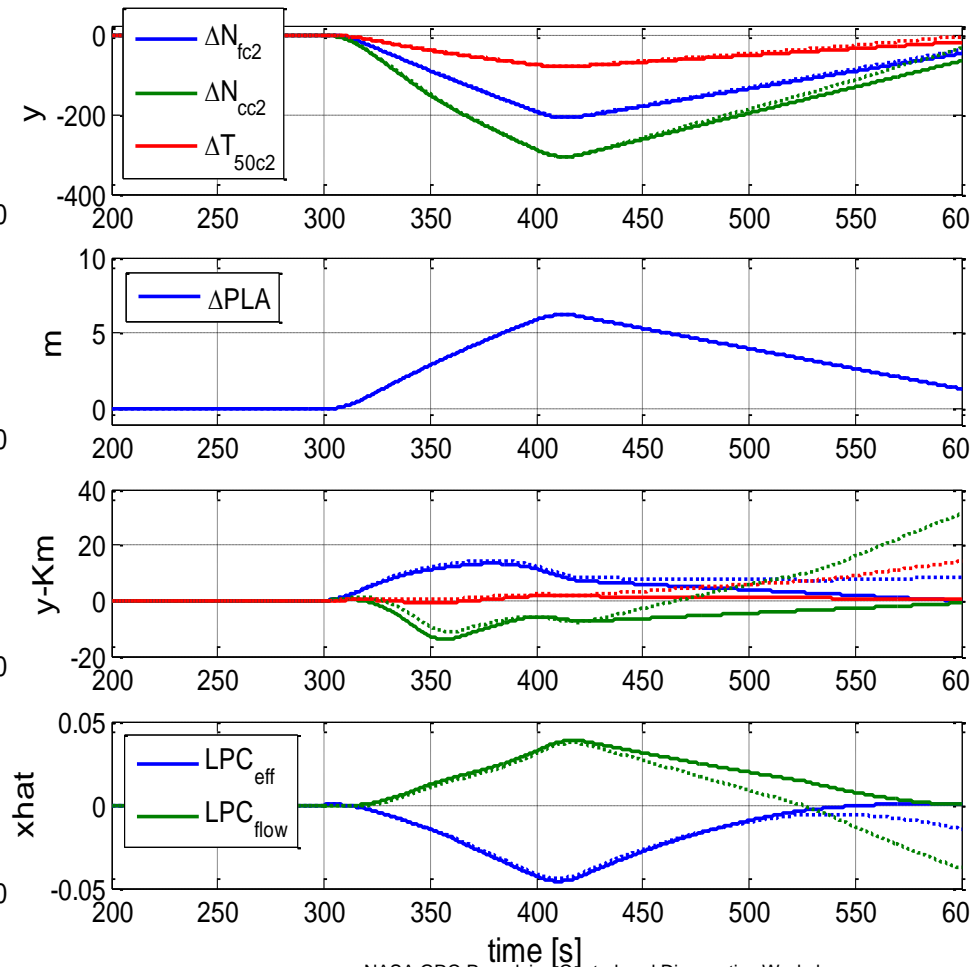
Detection of Engine Icing – Early Results



Decrease in Altitude



Decrease in Throttle



Mitigation of Engine Icing

- Ideally, completely avoid ice accretion
- If we can detect accretion can the engine controller act to mitigate the impact of the ice blockage?
- Potential mitigation strategies:
 - Operate actuators off-nominally to change operating point
 - » Close inter-compressor bleed valve or move HPC inlet guide vanes off schedule
 - Use existing airframe integration in novel ways
 - » Power take-off, Customer air bleed
 - Change shaft speed to cause ice to shed
- All of these approaches require iteration with an icing code to determine the effect of the new condition on ice accretion!

Future Plans

- Follow up on work done in NASA PSL
 - Complete development of model of Honeywell engine using T-MATS software
 - Implement & test detection algorithms on simulated engine
 - Verify against experimental data (mid 2014)
- Develop mitigation strategies – iterate with the NASA GRC icing code to determine how the change in operating point impacts the accretion of ice & possible testing in PSL

Acknowledgements

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References



- Jorgenson, P.C.E., Veres, J.P., May, R.D., Wright, W.B., "Engine Icing Modeling and Simulation (Part I): Ice Crystal Accretion on Compression System Components and Modeling its Effects on Engine Performance," 2011-38-0025, SAE International Conference on Aircraft and Engine Icing and Ground Deicing, Chicago, IL, Jun 13-17, 2011. doi:10.4271/2011-38-0025
- May, R.D., Guo, T-H., Veres J.P., Jorgenson, P.C.E., "Engine Icing Modeling and Simulation (Part 2): Performance Simulation of Engine Rollback Phenomena," 2011-38-0026, SAE International Conference on Aircraft and Engine Icing and Ground Deicing, Chicago, IL, Jun 13-17, 2011. doi:10.4271/2011-38-0026
- May, R.D., Guo, T-H., Simon, D.L., "An Approach to Detect and Mitigate Ice Particle Accretion in Aircraft Engine Compression Systems," ASME-GT2013-95049, ASME TurboExpo 2013, San Antonio, TX, June 3-7, 2013.
- May, R.D., Guo, T-H., Simon, D.L., "Detection of the Impact of Ice Crystal Accretion in an Aircraft Engine Compression System during Dynamic Operation," to be published at AIAA Guidance, Navigation, and Control Conference, National Harbor, MD, Jan 13-17, 2014.

